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FIFTH FORMAL REPORT

VHF QUARTZ CRYSTAL UNITS

October 1, 1962 - December 31, 1962

CONTRACT #DA-36-039-SC-85973
ORDER#6028-PP-61-81-81

PLACED BY:

U.S. Army Electronics Materiel Agency
Philadelphia 3, Pennsylvania

THE JAMES KNIGHTS COMPANY
SANDWICH, ILLINOIS

UNCLASSIFIED REPORT

FIFTH FORMAL REPORT

October 1, 1962 - December 31, 1962

PRODUCTION ENGINEERING MEASURES

VHF QUARTZ CRYSTAL UNITS
CR-(XM-38)/U
150 MC to 200 MC

SPECIFICATION SCS -75

CONTRACT #DA-36-039-SC-85973
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OBJECT OF STUDY: To perfect processes and testing techniques necessary to fabricate and evaluate 9th overtone crystal units in the HC-18/U holder in the frequency range of 150 MC to 200 MC to the above specifications, with a minimum of shrinkage without resorting to "screening."

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ABSTRACT

Data on 150 and 174 mc 9th overtone units, employing different electrode sizes is given. First efforts to adjust to frequency by etching the aluminum electrodes are reported. Data is given on holder resistance and inductance.

PURPOSE

The purpose of the contract is to develop techniques necessary to fabricate and evaluate 9th overtone units from 150 mc to 200 mc. The problems are (1) meeting the maximum series resistance specification of 80 ohms after adjustment to frequency, (2) correlation of our final frequency adjustment to the actual frequency as measured in the TSM-15, and (3) optimising yields sufficient to adhere to the requirement of "minimum shrinkage."

NARRATIVE AND DATA

Data on Effect of Electrode Size, and General Data

A series of experiments has been conducted to determine the effect of electrode size upon equivalent resistance. A few units in each electrode size had resistances well below the specified 80 ohms maximum. Data on several hundred units might show a somewhat greater yield for those employing larger electrodes, but nothing in the results of this series of experiments warrants departure from our usual practice of selecting electrode sizes which will produce a value of C_0 safely below the specified maximum of 7 pf. The data follows.

Table I gives the measurements made on 150 mc units with 0.150" electrodes. In addition to furnishing data on this electrode size, it shows that bonding in the case of these units in the McCoy tab clips, is a very large variable. One of the reasons for this is that these clips do not grip the quartz plate unless the spacing between the two sides of each clip is reduced. If, on the other hand, the clips are made tight, there is very bad scratching of the aluminum electrode tabs. The technique of the operators who readjust the clips and do this mounting is, then, a considerable variable. The second bonding was with a very small amount of DuPont 5504-A cement.

TABLE 1

150 MC UNITS 0.150" ELECTRODES

UNIT	Equivalent Series Resistance 9th Harmonic (ohms) Before Bonding	After Bonding	After Re-bonding	Cp (Boonton Rx meter) at 160 mc (pf)
1	very high	104	very high	5.31
2	72	79	59	5.92
3	dead	dead	very high	5.47
4	55	60	41	6.1
5	55	59	41	5.55
6	very high	100	dead	5.25
7	85	73	52	5.7
8	very high	dead	74	5.97
9	dead	---	---	6.07
10	very high	102	very high	5.8

UNIT	Holder Resistance after Rebonding (ohms)	Equivalent series Resistance on Other Harmonics after Rebonding 3rd	5th	7th
1	9.8	40	37	64
2	6.1	27	33	71
3	3.7	20	25	58
4	3.45	21	32	36
5	5.8	12	20	--
6	6.9	28	39	100
7	4.3	17	28	44
8	4.4	41	60	73
9	3.2	--	--	--
10	8.5	25	37	68

Table 2 gives the data on 150 mc, units, with 0.160" electrodes, before and after bonding. Measurements before bonding were made with slightly higher than the specified drive level, 0.36 volts across 60 ohms.

TABLE 2

150 MC UNITS   0.160" ELECTRODES
C_o=5.3 to 6.1 pf (measured at 1 mc.)

Unit	Equivalent Series Resistance Before Bonding (ohms)	Equivalent Series Resistance After Bonding (ohms)
1	87	70
2	60	62.5
3	very high	very high
4	75	67.5
5	45	48
6	very high	very high
7	dead	dead
8	52	52
9	56.5	61
10	49	48
11	67	65
12	very high	very high
13	67	very high

In Table 3, the 150 mc units with 0.180" electrodes were read before bonding with a drive of 0.36 volts across 60 ohms.

TABLE 3

150 MC UNITS   0.180" ELECTRODES

C_0=7.3 to 7.5 pf (measured at 1 mc.)

UNIT	EQUIVALENT SERIES RESISTANCE BEFORE BONDING	EQUIVALENT SERIES RESISTANCE AFTER BONDING
1	53.5	56
2	70.5	75
3	40	45
4	38	45
5	very high	very high
6	67	65
7	69	65
8	53.5	77.5

The 174 mc. units measured in connection with this experiment had 0.180" electrodes. Other electrode sizes were planned, but the results with the 150 mc. units seemed adequate, and the additional blanks prepared at 174 mc. were reserved for other experiments. After these 174 mc. units with 0.180" electrodes were bonded, the holder and bond resistance rose to very high values, mostly between 10 and 65 ohms. Table 4, therefore, gives only the measurements made before bonding. It is to be noted that these unbonded units did not necessarily maintain the same contact between clips and plated tabs, and that, therefore, the R_h values given are not necessarily the R_h values when the various dynamic resistances were measured.

TABLE 4

174 MC UNITS 0.180" ELECTRODES
NOT BONDED

C_o=6.15 to 8.57 (measured at 1mc)

UNIT	EQUIVALENT SERIES RESISTANCE FUNDAMENTAL	3rd	5th	9th	RX METER AT (180 mc) C_p (pf)	R_h (ohms)
1	12	31.5	43	60	9.80	4.0
2	12.5	11	20	52	9.85	4.5
3	7.5	15.5	38	83	9.90	4.1
4	7.5	22.5	30.5	50	9.47	5.4
5	12.5	14	35.5	56	9.45	4.1
6	5	13	46	47	9.70	3.0
7	7.5	14.5	24.5	45	9.80	3.6
8	6	16.5	33.5	73	9.80	5.65
9	5.5	15.5	33.5	56	9.52	4.1
10	5	12	33.5	60	10.00	4.3
11	9	11	29	88	9.85	3.2
12	5	12.5	38.5	60	9.60	3.9
13	11	14	24.5	64	9.90	5.8
14	4.5	11.5	39.5	41	9.80	4.0
15	5.5	16	18	52	9.85	6.1
16	6	10.5	12.5	40	9.80	5.15
17	11	13.5	47.5	74	10.10	3.95

As a side note on Tables 1, 2, 3, and 4, it is interesting to note that of 48 units, 11 were measured below 51 ohms, 11 were in the 51-60 ohm range, 8 in the 61-70 ohm range, 5 in the 71-80 ohm range, 2 in the 81-90 ohm range, none in the 91-100 ohm range, and 11 units had very high resistance. One cannot, however, base a statistical conclusion upon 48 units.

Holder Parameters

Tables 5 and 6 give the Boonton RX measurements of the crystal units as capacitors, at several frequencies off resonance. Inductance has been calculated only at 100 and 160 mc.

It is to be emphasized that all of the parameters being discussed under this heading, C_p, R_p, R_h, L_h, and Q are parameters of the crystal unit (quartz plate, electrodes, mount, and holder), measured off resonance so that the unit appears as a capacitor with certain resistances and inductances introduced by the connecting members. R_h includes, for example, the resistance of the electrodes, of the connecting tabs, of the bond, and of the mounting supports and wire leads.

The RX meter measures two parameters, the parallel capacitance or inductance (capacitance in this case) and the parallel resistance. The equations are as follows:

$$X_p = \frac{1}{\omega C_p} \qquad Q = \frac{R_p}{X_p} \qquad R_s = \frac{R_p}{1+Q^2}$$

where the subscripts "p" and "s" stand for parallel and series, respectively. R_s, which in this case, we interpret as R_h (holder and mount resistance) does not include the resistance of the motional arm of the crystal, and X_p does not include the reactance of the motional arm. There is, then no relation between Q as used here and the Q of the resonator unit, except

that they have one common component: R_h is the resistance calculated from the Q of the crystal unit viewed as a capacitor, and it is a part, but not all, of the resistance which degrades the Q of the crystal unit measured as a resonator.

The holder inductance, L_h, is calculated as follows:

It is assumed that L_h is negligible at 1 mc. and that, therefore, C_p measured at 1 mc is the true parallel capacitance.

Then: $$L_s = \frac{1}{(2\pi f)^2}\left(\frac{1}{C} - \frac{1}{C_p}\right)$$

where L_s is the series inductance (called L_h in this discussion, or holder inductance); f is the high frequency, near, but not at the resonant frequency of the crystal unit; C is C_p measured at 1 mc; C_p is C_p measured at f.

In practice, greater accuracy can be obtained by measuring C_p at points well below and well above the resonant frequency and plotting a curve through the resonant frequency.

For greater accuracy, C_p can be corrected for the series inductance of the binding posts of the meter:

$$C_p \text{ (true)} = \frac{C_p}{1+(\omega^2\ 0.003\times10^{-6}\ C_p)}.$$

L_h can be corrected by subtracting 0.003×10^{-6} henries from the values calculated with the uncorrected value of C_p, or L_h may be calculated from C_p (true). These corrections are not

made in the following tables. The true L_h value is, therefore, 0.003×10^{-6} henries less than that shown. There is, however, an uncertainty in these figures of about $\pm\ 0.002 \times 10^{-6}$ henries.

It is clear from the uncorrected L_h values in the tables that the short McCoy tab clip makes it possible to meet the specification, L_h not to exceed 0.02 micro-henries. It is also clear that, although there was some difficulty with the bond, this mount does not result in excessive resistance at high frequencies. The specification allows a maximum of 7 ohms. It will be noted that, except where the bond was imperfect, the increase of R_h with frequency, resulting from skin effect, was very small.

Unit 12 in Table 6 can be taken as a clear example of a bad bond. The value of R_h is nearly 10 ohms at 100 and 140 mc, and jumps to 28 ohms at 160 mc (probably instable bond). At the same time the C_p readings (parallel capacitance) remain almost constant, instead of increasing with frequency as they should do as a result of L_h. Usually units showing even less evidence of bad bonding than this, if examined with a dc ohmeter, are found to have an open circuit on one or both sides. Therefore the crystal unit appears to the RX meter, not as a single capacitor, but as two or more capacitors in series connected by high resistances. The data given in

Tables 5 and 6 was taken without covers on the units. In order to check the data, a sealed unit was remeasured at 55, 80, 100, 120, 140, 160, 180, and 200 mc. The measured values of C_p and R_p, and the calculated values of Q, R_h, and L_h are shown in Figure 1. Theoretically L_h should remain the same. The apparent slope from about 0.008×10^{-6} at 70 mc to about 0.012×10^{-6}, at 200 mc, amounts to 0.004×10^{-6}, and probably results from systematic measurement error. A second unit (174 mc, 0.180" electrodes, pin hole unsealed) yielded the following:

Frequency of Measurement	Cp (pf)	R_p (ohms)	X_p (ohms)	Q	R_h (ohms)	L_h $hx10^{-6}$
1 mc	8.12					
100 mc	8.39	14,000	190.0	74.6	2.50	.017
200 mc	9.78	1,949	81.4	24.0	3.35	.015

FIGURE 1

HOLDER PARAMETERS vs FREQUENCY 150 MC 9th OVERTONE
Diameter 0.275" Electrode .160"
McCoy Tab-clip Mount

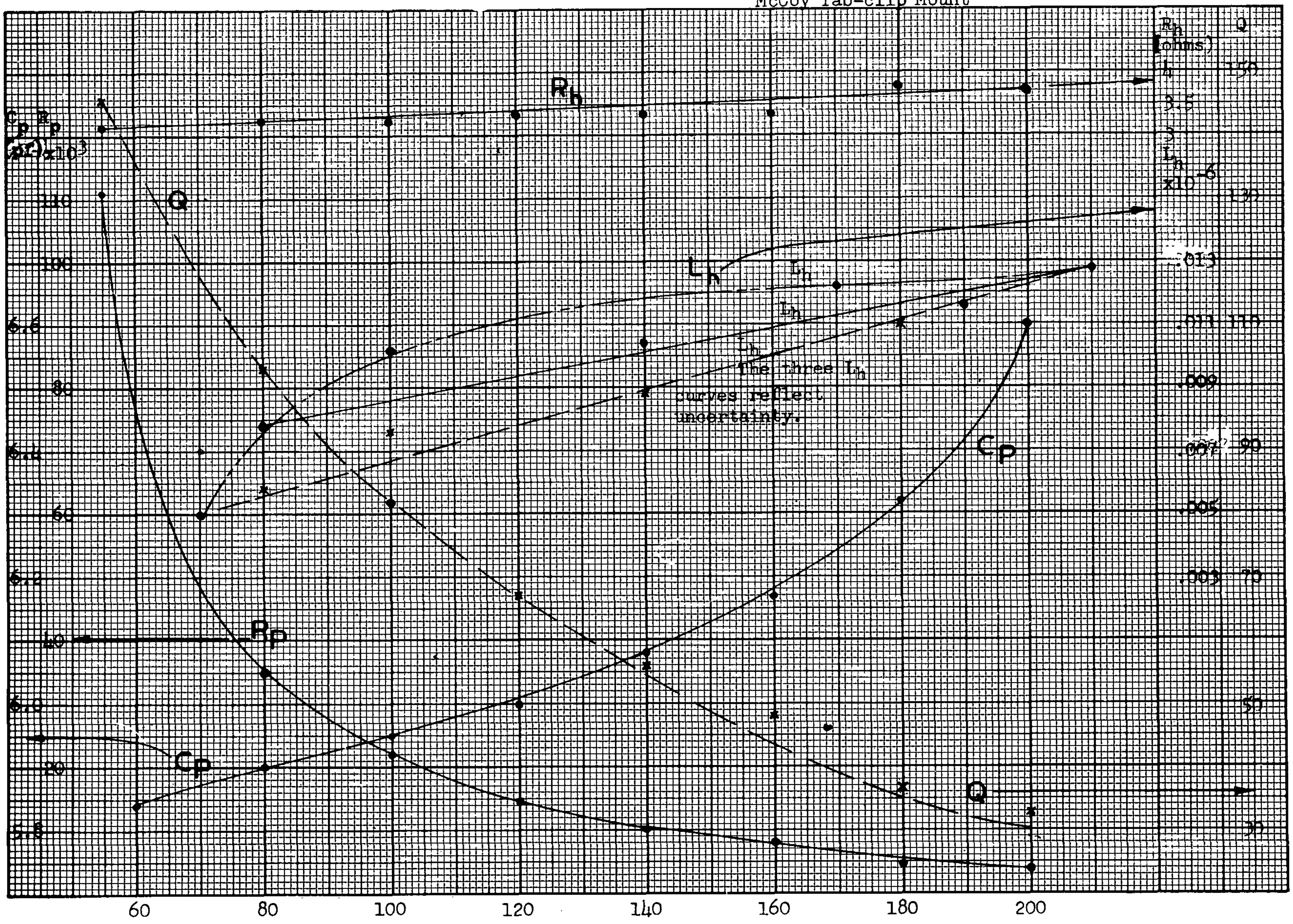


TABLE 5

MEASUREMENTS OF 150 MC 9th HARMONIC UNITS ON RX METER ELECTRODE

DIAMETERS 0.160" and 0.180"

Electrodes 0.180"

UNIT	F (mc) of measurement	Cp (pf)	Xp (ohms)	Rp (ohms)	Q	R_h (ohms)	L_h (henries x10^{-6})
2	1	7.30					
	100	7.47	213.0	26,000	122.0	1.8	.010
	140	7.72	147.5	6,650	45.1	3.3	---
	160	7.95	125.0	6,120	49.0	2.6	.013
4	1	7.30					
	100	7.40	215.0	4,200	19.5	11.0	.007
	140	7.60	149.5	1,850	12.4	12.0	---
	160	7.75	128.0	1,430	11.2	11.3	.009
5	1	7.40					
	100	7.58	210	10,500	50.0	4.2	.009
	140	7.90	144	3,770	26.2	5.5	---
	160	8.00	124	2,850	23.0	5.7	.012
8	1	7.10					
	100	7.50	212.0	23,500	111.5	1.9	.019
	140	7.80	145.5	6,280	43.1	3.4	---
	160	7.95	125.0	3,290	26.3	4.8	.017

Electrodes 0.160"

UNIT	F (mc) of measurement	Cp (pf)	Xp (ohms)	Rp (ohms)	Q	R_h (ohms)	L_h (henries x10^{-6})
1	1	5.95					
	100	6.23	255.0	50,000	196.0	1.3	.019
	140	6.48	175.5	12,000	68.4	2.6	---
	160	6.53	152.0	7,580	49.8	3.1	.017
2	1	5.80					
	100	6.06	262	41,000	156.5	1.7	.015
	140	6.32	180	6,400	35.5	5.1	---
	160	6.33	157	1,820	11.6	13.6	.016

MEASUREMENTS OF 150 MC 9th HARMONIC UNITS ON RX METER ELECTRODE

DIAMETERS 0.160" and 0.180"

Electrodes 0.160" continued

UNIT	F(mc)of measurement	Cp (pf)	Xp (ohms)	Rp (ohms)	Q	Rh (ohms)	Lh (henries x10^{-6})
6	1	5.80					
	100	6.10	260.5	32,500	124.8	2.11	.022
	140	6.45	176.5	6,900	39.1	4.50	---
	160	6.56	151.2	4,320	28.6	5.30	.023
12	1	5.90					
	100	6.05	262.5	7,100	27.0	9.8	.011
	140	6.35	178.5	3,250	18.2	9.9	---
	160	6.20	160	885	5.5	28.1	.010

Frequency Spread and Frequency Adjustment

The sample blanks which were ordered with different electrode sizes were specified for a maximum spread after base plating of:

150 mc.	40 kc on the fundamental
174 mc.	46 kc on the fundamental

The actual spreads achieved on the samples were 21 kc and 37 kc, indicating that control through base plating can be adequate.

In this connection, it is worth mentioning that the differences between the ninth harmonic frequency and nine times the fundamental frequency was much greater than had been anticipated. From data in our possession on 12 mc fundamentals, 0.350" in diameter, operated at 60 mc we arrive at the following:

$$\text{For} \quad \frac{d_e^2}{t} = 9.6 \quad , \quad \frac{5f_1}{f_5} = 0.998325$$

Where d_e is the electrode diameter, and f the thickness of the plate, f_1 the frequency on the fundamental, and f_5 the frequency on the fifth harmonic, the 174 mc units, 0.275" in diameter, very lightly plated (see below), and with a value of de^2/t of 9.6, resulted in:

$$9f_1/f9 = 0.997793 \text{ to } 0.997961$$

a much greater difference from the 5th harmonic than had been anticipated. This makes a difference, of 40 kc between the actual fundamental corresponding to a ninth harmonic of 174 mc, and 174/9, a quite significant amount.

The effort with these experimental units was to hold the

base plating to $0.15F^2$. Despite the very thin plating, an effort was made to adjust their frequency by etching the aluminum plating with a weak solution of potassium hydroxide. The entire unit was dipped in the solution. It was found possible to control the frequency in small increments, but the plating was too thin to permit much frequency adjustment. Of the six units etched, four increased in activity at first, and then decreased very rapidly. Three of these four units were dead or nearly dead before the first etching.

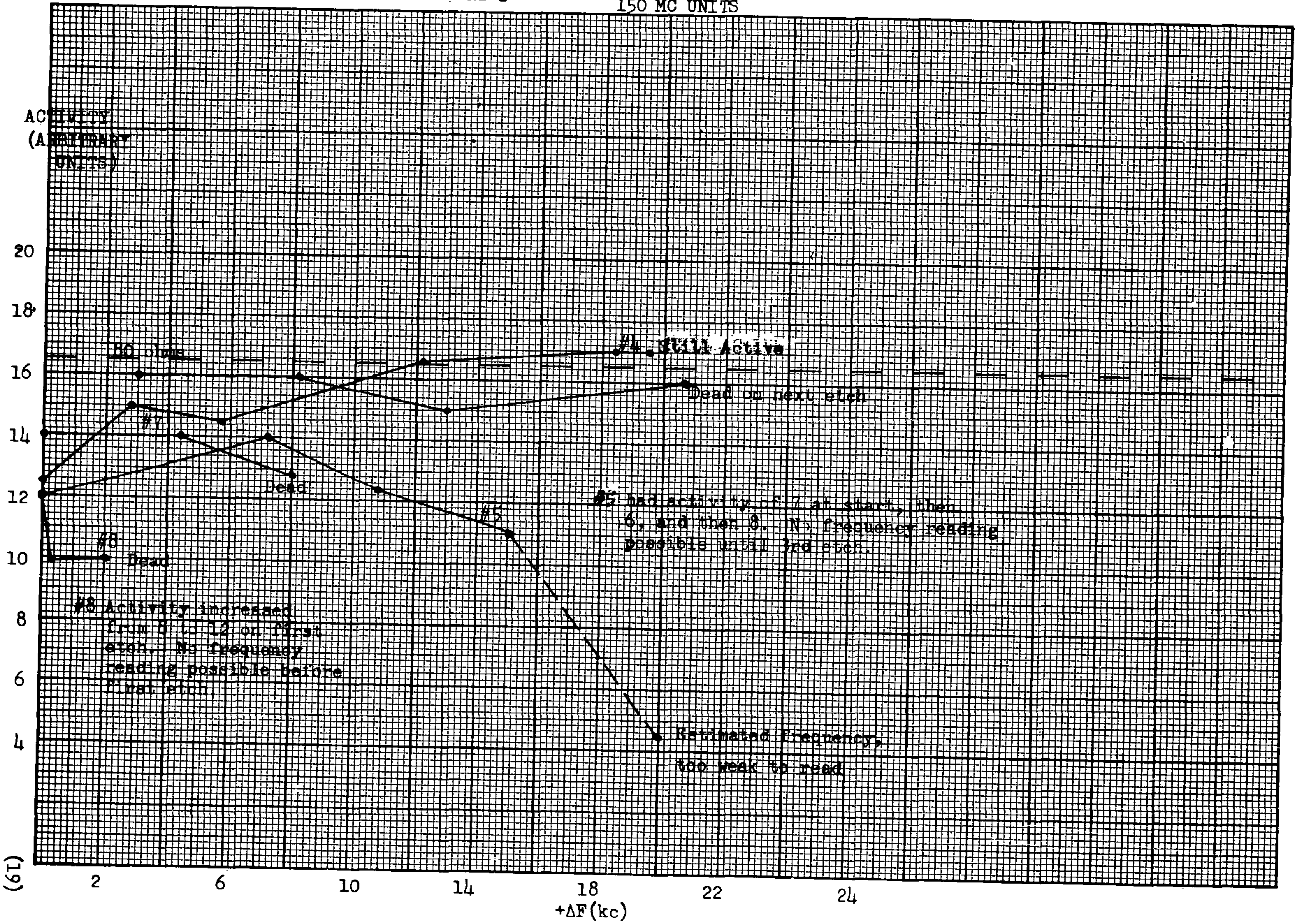
There are a number of factors involved. It is probable that the plate-back curve (ΔF vs R) for 9th overtone units at 150 mc is quite sharp. The plating on these units was very thin, and it was somewhat thinner on one side than on the other. The method used removed aluminum from the connecting tabs as well as from the electrodes proper, and this was more serious because the tabs were frequently in a scratched condition resulting from difficulties with inserting them in the tab-clip mounts. Moreover, there may have been some cleaning action associated with the first increments of etch.

It would appear to be desirable to collect the data for a plate-back curve for 9th overtone units as a basis for further experiments, and for specifying the amount of plating required for units which are to be etched to frequency.

Figure 2 shows the results of the first experiment. It is to be emphasized that this was a first experiment, made with units which had been much too lightly plated.

FIGURE 2

ETCH (WEAK POTASSIUM HYDROXIDE)
OF ALUMINUM ELECTRODES
150 MC UNITS



CONCLUSIONS

It is possible to make 150 mc and 174 mc 9th overtone units with resistances well below the specified maximum of 80 ohms if some means can be found of adjusting them to frequency without much increase in resistance. Electrodes may be designed to give values of C_0 at least as low as 6pf, without any disastrous increase in resistance. Experiments conducted so far have not employed enough units to permit a statistical estimate of yields, and we are further handicapped by the fact that units with resistances above 80 ohms tend to have very high resistances, beyond the range of the TSM-15. It is clear, however, that a significant number of units belong in the "very bad" category, for reasons which are not yet understood.

Achieving a good mount and bond, without excessive scratching of the electrodes, is more difficult than could have been anticipated. This is partly a result of difficulties with the small, short McCoy version of the tab-clip mount. This mount, however, makes it possible to meet the maximum holder resistance and holder inductance specifications of this project.

PROGRAM FOR THE NEXT QUARTER

An effort will be made to gather adequate data for a plate-back curve and to establish values and a process for etching to frequency. At the same time the orientation angle for 75° control will be checked. Pre-production samples can follow the completion of the above.

PUBLICATIONS, REPORTS, AND CONFERENCES

A fourth quarterly report was published and distributed, and monthly letter reports for September, October, and November were submitted.

TECHNICAL PERSONNEL CHARGING TIME

R. BENNETT	175 hours
L. DICK	7 hours

FABRICATION LABOR

SAWING & LAPPING	74.5 hours